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Ice Engineering

U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

Ice Events in the Susquehanna River Basin

As is true for many other rivers in the northern United States, those within the Susquehanna River Basin are subject to ice events that cause flooding; damage riverine structures such as dams, bridges, dikes, levees, and wingwalls; block hydropower and water supply intakes; and decrease downstream discharge. Roads may be flooded and closed, or bridges weakened or destroyed, limiting emergency and medical relief to the affected areas. The potential exists for death or serious injury caused by jam and flood conditions, and during evacuations and other ice mitigation operations. Also, ice movement and ice jams can severely erode streambeds and banks, with adverse effects on fish and wildlife habitat.

The lack of readily available information on historical ice events hinders rapid, effective response to ice-related flooding and other damage, and also prevents an accurate assessment of damages, which are estimated to cost more than $100 million annually in the United States. Engineers and state officials work together to prevent damages caused by these events, and many are working to anticipate future measures required to prevent serious events from forming.

These efforts depend upon accurate and reliable data that can be used to research previous ice events, to predict and assess conditions that may increase the probability of an ice jam formation, and to document steps taken by engineers and relief officials in previous years when confronted with ice jam conditions during emergency situations. The CRREL Ice Jam Database was developed to provide a centralized record of ice events, and now contains information on nearly 12,000 events.

Database entries include the name of the water body; the city and state where the ice event took place; date of the event, if known; the ice event type, if known; a brief description of damage; the names of CRREL and Corps personnel familiar with the event or site; reference to visual records of the event, if available; latitude and longitude; USGS gage number, if available; and hydrologic unit code.

Records also contain narrative descriptions of ice events (some of which can be several pages) and a list of information sources. There is a separate database entry for each discrete ice event at a given location. Many entries rely on yearly USGS Water Resource Data Reports and other USGS gaging station data. Information also comes from newspapers, books, historical records, trip reports, and other historical accounts of ice jams. The database is useful for characterizing ice jams for specific areas and for providing information during emergency ice jam flood situations.

This *Ice Engineering Information Exchange Bulletin* provides a brief summary of CRREL's Ice Jam Database entries for the Susquehanna River Basin, including a number of historical ice events (Fig. 1).

Figure 1. Susquehanna River at Wilkes-Barre, Pennsylvania, 1875 ice jam. (From Murphy et al. 1905.)

Susquehanna River Basin

The Susquehanna River Basin drains approximately 27,200 mi^2 in the 447 miles between its source at Hayden Creek in Otsego County, New York, and its confluence with Chesapeake Bay at Havre de Grace, Maryland (van der Leeden et al. 1990). Major tributaries include the West Branch Susquehanna River are underreported, particularly if the events are short-lived, occur at night, and/or affect a small area. Data sources other than the USGS include National Weather Service Bulletins, CRREL trip reports, and newspaper articles. Only three of the entries for the Susquehanna River Basin (for 1832, 1904, and 1996) provide damage cost estimates, highlighting the need for increased reporting of damages.

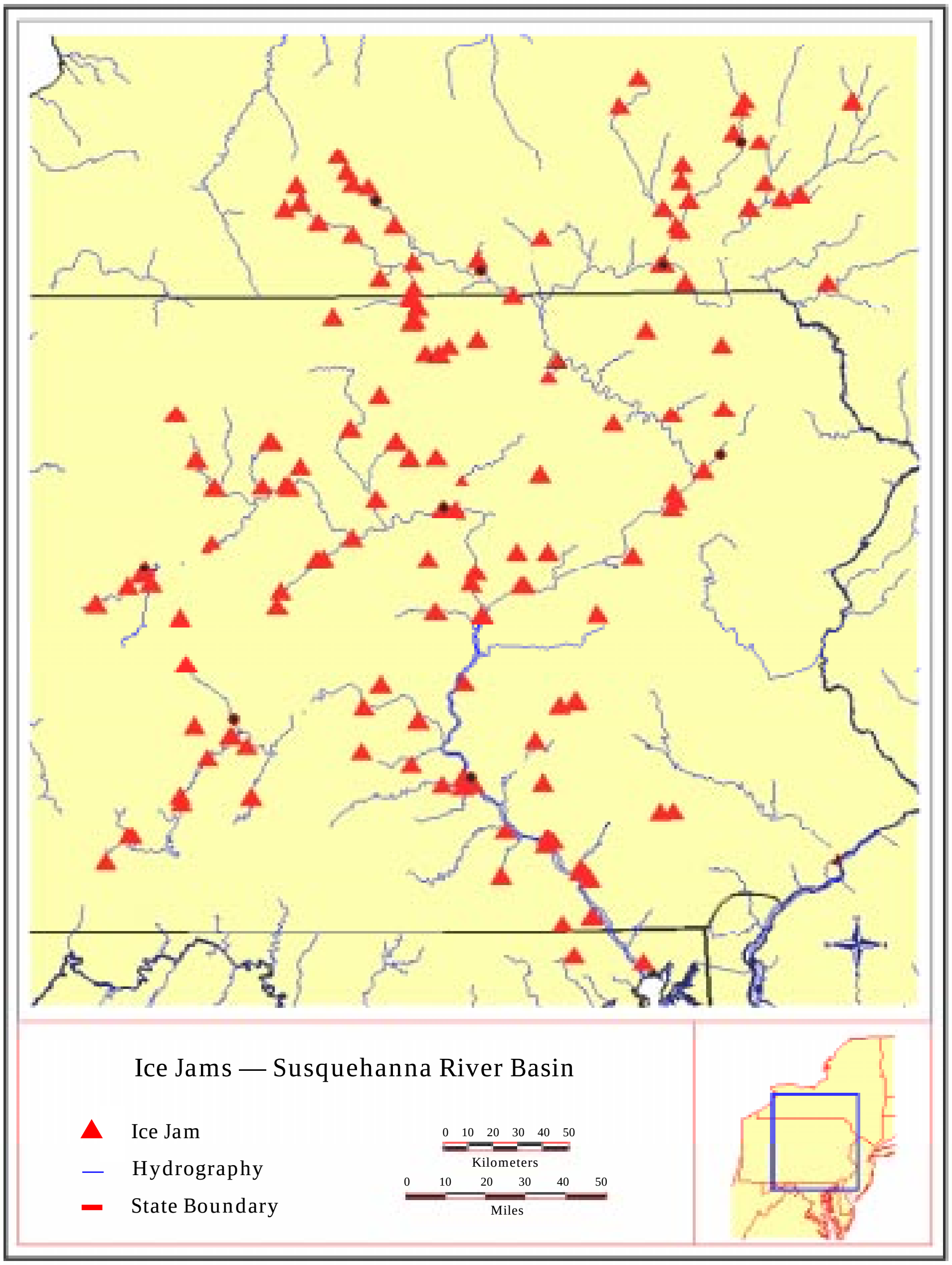

Figure 2. Reported ice event locations in the Susquehanna River Basin.

(6847 mi^2), North Branch Susquehanna River (4773 mi^2), the Juniata River (3354 mi^2), and the Chemung River (2506 mi^2) (Fig. 2). The river basin lies within the U.S. Army Corps of Engineers Baltimore District, which operates 14 flood control projects on tributaries, four of which are located in New York and 10 in Pennsylvania.

As of September 1998, 503 ice events that occurred between 1784 and 1997 within the Susquehanna River Basin were documented in the CRREL Ice Jam Database. One event took place in the 1700s, 11 in the 1800s, and the rest in the 1900s. A substantial amount of the information on these events was obtained from the USGS (80.5%), compared to about 85% for the database as a whole. As a result, the spatial and temporal biases associated with heavy reliance on USGS data that affect much of the database may still affect the entries for the Susquehanna River Basin. Essentially this means that ice events that occur away from USGS gages and in remote or poorly accessible locations

Where do ice events occur in the Susquehanna River Basin?

The database contains information on ice events at 151 different locations on 93 rivers and streams in New York, Pennsylvania, and Maryland (Fig. 3 and 4). Pennsylvania had the most reported ice events (377), followed by New York (122) and Maryland (4). The most events (89) occurred on the Susquehanna River. Other rivers with more than 20 reported ice events are the Chenango River in New York (22), the West Branch Susquehanna River (44) and Pine Creek (31) in Pennsylvania, and the Tioga River (22) in both Pennsylvania and New York.

The highest number of ice events at one location has been recorded at Harrisburg, Pennsylvania (21), partly because of the long-term records available for that location. According to Mangan (1936), systematic stage observations at Harrisburg began 1 January 1874. Cedar Run (Pine Creek) and Dimeling, Pennsylvania (Clearfield Creek), are next with 17 events each. USGS gages are located at both of these sites.

When do ice events occur in the Susquehanna River Basin?

The years with the highest numbers of reported ice events are 1959, with 35, followed by 1965 (28), 1982 (27), and 1966 (22). Although some reports indicated as many as 50 ice events in 1996 (see below), specific information was located for only 17 events.

Most ice events in the Susquehanna River Basin have occurred in January, although February and

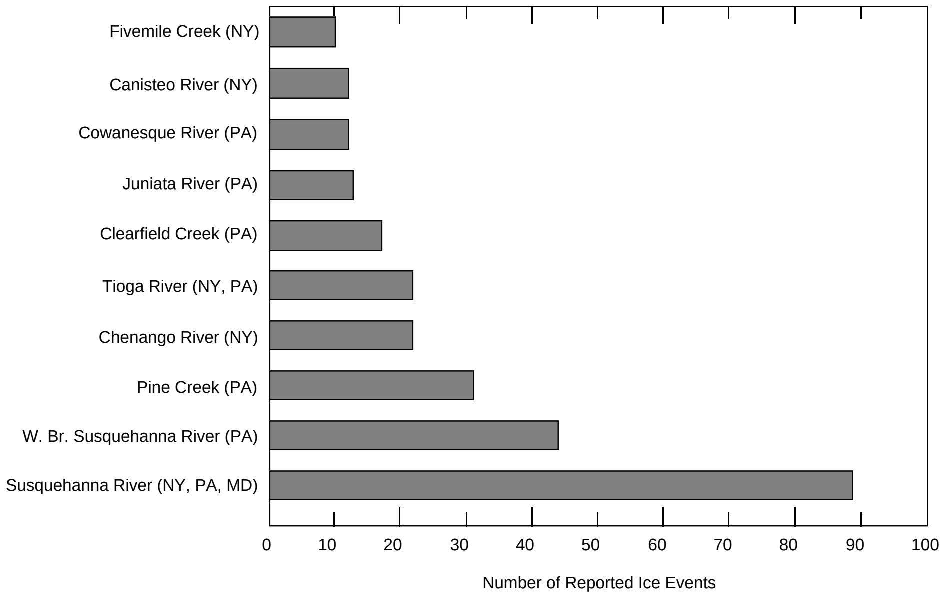

Figure 3. Rivers in the Susquehanna River Basin for which five or more ice events are reported.

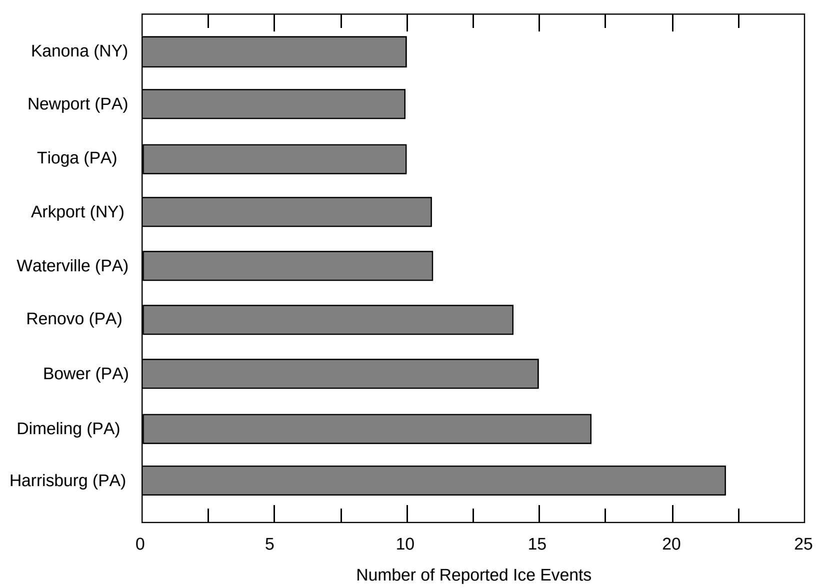

Figure 4. Locations reporting five or more ice events in the Susquehanna River Basin.

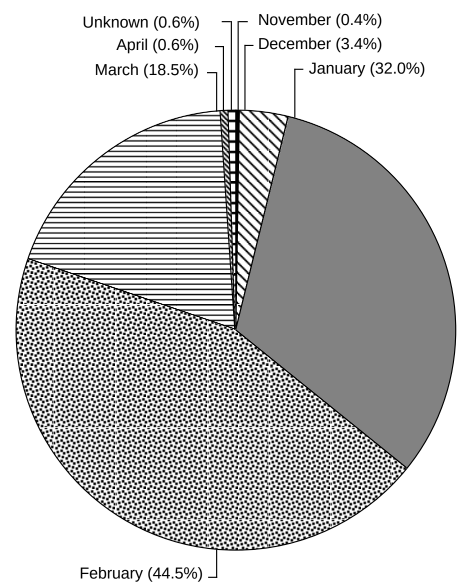

Figure 5. Monthly distribution of reported ice events in the Susquehanna River Basin.

March also have had significant numbers of events (Fig. 5). Ice events have occurred as early as November (two) and as late as April (three). Dates are unknown for three of the reported events.

The significant ice-jam flooding of March 1904 (Fig. 6) was caused by the breakup and jamming of ice during January, followed by a period of cold during which the jams froze in place and additional ice grew. Warm rainy weather on 6 and 7 March caused water levels to rise, breaking up the previous jams and forming new ones (Murphy et al. 1905). Murphy states, "This flood was not due to the large volume of water flowing in the river, but to the ice gorges [jams] in it." Other significant ice jams occurred during February and early March 1936 (Fig. 7). Colder than normal air temperatures in December and January resulted in a thick ice cover. A February thaw broke up some ice, but runoff was insufficient to break up and move all of the ice. Some jams formed then and remained in place until heavy rainfall on a deep snowpack occurred in early March, causing high stages that persisted until the runoff was heavy enough to fail the jams (Grover 1937).

Similar weather conditions led to the January 1996 flood event (Eames 1997), when the state of Pennsylvania experienced the most severe statewide flooding since tropical storm Agnes in June 1972 (USGS 1996). Early cold temperatures resulted in ice cover formation in December, followed by unusually large snowfall (2–3 ft above normal) in early January. Beginning 18 and 19 January, strong winds and dew points reaching into the 50s caused massive runoff from this snowpack, which had a water equivalent of three to four inches (Kelley 1996). Conditions were exacerbated when rainfall associated with a cold front moved in on 19 and 20 January (http://marfcws1.met.psu.edu/Flood/). According to the USGS (1996), the magnitude of the January 1996 floods was increased by ice jams at approximately 50 locations throughout the state of Pennsylvania.

Figure 6. Ice jam flood, 8 March 1904, at York Haven, Pennsylvania. (From Murphy et al. 1905.)

Figure 7. Ice on the Susquehanna River in Dauphin County, near Harrisburg, Pennsylvania, March 1936. (From Grover 1937.)

Who is affected by ice events in the Susquehanna River Basin?

From the data collected for inclusion in the CRREL Ice Jam Database, it appears that ice events in the Susquehanna River Basin cause most damage to individuals, followed by municipalities and hydropower companies. Ice-related damages include flood damage and structural damage to roads, bridges, dams, wingwalls, levees or dikes, and other riverine structures.

Because more than 60% of hydropower capacity in the state of Pennsylvania is located within the Susquehanna River Basin, ice effects on dams and related structures can be important. Among the larger hydropower installations in the basin are Safe Harbor (417.5 MW) in Pennsylvania and Conowingo (512 MW) in Maryland.

Safe Harbor has experienced a number of damaging jams. Two of the worst events took place in 1978 and 1996. On 27 January 1970, ice from jams that failed upstream from the dam flowed past the dam only to jam downstream. By 29 January, the resulting backwater had reached an elevation of 202.5 ft, 7.5 ft above the generator room floor (Harza Engineering Company 1981). The powerhouse was out of service until mid-April of that year at a substantial cost both in terms of repairs and of lost generation.

In January 1996, a surge of ice and water resulting from the sudden failure of an upstream jam at Turkey Point raised the average daily flow to 826,000 cfs on 20 January. Downstream from the Safe Harbor Dam, the Conowingo Dam, and eventually the City of Port Deposit, Maryland, also were affected by the wave of water. Port Deposit experienced severe flooding and was reported to have only half an hour of warning time.

Ice event damages in the Susquehanna River Basin

Few ice event reports in the Susquehanna River Basin include information on estimated damage. (This is true for the database as a whole.) More attention must be paid to gathering these types of data in the future in order to document the scale of costs associated with ice events in a manner similar to that done for open-water flood events. Because of their short duration and highly localized extent, the costs associated with ice-related floods are often neglected or underestimated, although they can easily equal the magnitude of open-water floods.

In his account of the 1904 ice event, Murphy attributed much of the damage to the surge of ice and water resulting when the ice jams failed. Newspaper damage reports listed about $8 million (in 1904 dollars!) in damages, including flood damage to houses, businesses, railways, and

Figure 8. Ice deposited along Front Street, Harrisburg, Pennsylvania, January 1996. (Courtesy National Weather Service Middle Atlantic River Forecast Center.)

agricultural land and structural damages to bridges, houses, railroads, and roads (Murphy et al. 1905).

Such surges also caused large damages during the 1996 ice event. On the Susquehanna River at Safe Harbor, with a 75-year average flow of 38,300 cfs (Kelley 1996), the surge resulting from the failure of the Turkey Point ice jam caused an estimated $20 million in damage at Safe Harbor Dam, which was built in 1930 (Safe Harbor 1996). These costs included damage to a $14-million construction project at the downstream side of the dam and the destruction of a skimmer wall that had withstood many ice events since construction in 1930.

The 1996 Susquehanna River ice event also caused much damage in Harrisburg, Pennsylvania (Fig. 8), including the failure of the Walnut Street Bridge. This bridge, built in 1888, had withstood many ice and flood events, including the ice events of 1970 and 1971 (during which it was closed as a precautionary measure) and the open-water flood of 1972, which had a higher stage (USGS 1996). The superstructure of the bridge was lifted off its piers and carried downstream on top of the moving ice jam until it was destroyed as it was forced beneath another bridge.

Ice monitoring in the Susquehanna River Basin

The National Weather Service (NWS) has two weather forecast offices in the Susquehanna River Basin—one in Binghamton, New York (WFO BGM), and another in State College, Pennsylvania (WFO CTP)—that are responsible for the collection of hydrologic data and the public issuance of river forecasts and flood warnings in their respective areas. The NWS Middle Atlantic River Forecast Center (MARFC), also located in State College, supports the hydrology programs at WFO BGM and WFO CTP by providing routine river and flood forecast guidance for numerous river locations in the Delaware and Susquehanna River Basins.

Snowmelt/runoff events that result in ice jams pose difficulties to the hydrologic forecaster in addition to those posed by open-water flood events. Following the damaging floods of 1996, the MARFC determined that obtaining additional river ice observations during both river ice accumulation and breakup periods would be of significant benefit to the NWS hydrology programs at the MARFC, WFO BGM, and WFO CTP.

The MARFC requested assistance from CRREL to provide training for WFO BGM and WFO CTP river ice observers in order to provide safe, accurate, and consistent reports of river ice conditions. During the fall of 1996, CRREL and MARFC presented two half-day workshops at Binghamton, New York, and Sunbury, Pennsylvania, for NWS ice observers. Each workshop was designed so that the observers obtained a basic understanding of the various processes of river ice cover formation, growth, breakup, and jamming. Safety was a primary topic as all NWS river observations for the WFO BGM and CTP offices are to be taken a safe distance away from the river. Visual ice observation methods and the appropriate terminology to describe ice events were introduced. The NWS observation form was reviewed to ensure accurate and consistent reporting by observers, with participants viewing selected ice-related slides and reporting their observations using the NWS form.

As a result of this effort, the NWS has developed an expanding network of river ice observers to provide accurate and consistent reports of current river ice conditions in the Susquehanna River Basin. WFO CTP river ice reports are available real-time by accessing http://bookend.met.psu.edu/hydro.html and WFO BGM ice reports are available at http://tgsv5.nws.noaa.gov/er/bgm/hydro.html.

In addition to initiating the river ice observer networks, the MARFC and CRREL collaborated on a comprehensive survey of the meteorological and hydrological conditions associated with historic jam events, of which this report is a part. This study collected information on historic ice events in the Susquehanna Basin for later analysis of hydrological and meteorological data to identify the conditions likely to result in ice jams within the basin.

How is ice jam information helpful?

This overview of ice events in the Susquehanna River Basin summarizes data collected as part of a study of the meteorology and hydrology of ice events within the basin. Historical meteorological and hydrological data for a number of locations within the basin are presented in graphical form at http://www.crrel.usace.army.mil.ierd/susqu/. These types of historical data are crucial during emergency situations when information about ice jam locations or stages would be helpful. They also are useful for predicting ice jams. For example, if weather conditions similar to those in 1996 occur in the future, one can access information on ice jams in 1996 to determine the most likely jam areas and thus carry out appropriate mitigation techniques.

CRREL also has an Ice Jam Archive that contains hard copies of the NWS reports, newspaper articles, and other reports used as sources for this and other ice-related studies (Herrin and Balch 1995). The documents can be checked out or photocopied for research.

Acknowledgments

The author thanks Erika K. Peterson, Engineering Aid, who collected, organized, and entered into the CRREL Ice Jam Database much of the information on Susquehanna River Basin ice events. Lourie A. Herrin, Program Assistant, and Deanna Kasperski, an intern with the Dartmouth College Women in Science Program (WISP), also helped gather and enter data. Ned Pryor of the NWS Middle Atlantic River Forecast Center was instrumental in obtaining funds to collect data, and also provided much information.

The study was supported by funding from the National Weather Service Middle Atlantic River Forecast Center, State College, Pennsylvania, and by USACE Civil Works Cold Regions Engineering Program Work Unit *Field Monitoring of Ice Jams*.

Please send any information for inclusion in the Ice Jam Database or Ice Jam Archive to Lourie Herrin, Ice Engineering Research Division, CRREL, 72 Lyme Road, Hanover, NH 03755-1290. Originals can be photocopied or scanned and returned. The CRREL Ice Jam Database is available via CRREL's Web site (http://www.usace. army.mil).

References

Eames, H.J. (1997) Ice jams, winter 1995–96. *Ice Engineering Information Exchange Bulletin*, Number 17, U.S. Army Cold Regions Research and Engineering Laboratory.

Grover, N.C. (1937) The floods of March 1936, Part 2: Hudson River to Susquehanna River region. Water-Supply Paper No. 799, USGS: Washington, DC.

Harza Engineering Company (1981) A study of the ice jam problem at the Safe Harbor Hydroelectric Project. Report prepared for the Safe Harbor Water Power Corporation.

Herrin, L.A., and E.M. Balch (1995) Introducing the Ice Jam Archive. *Ice Engineering Information Exchange Bulletin*, Number 10, U.S. Army Cold Regions Research and Engineering Laboratory.

Kelley, H.V. (1996) Safe Harbor survives. *The Safe Harbor Spillway*, January/February 1996.

Mangan, J.W. (1936) The floods of March 1936 in Pennsylvania. Commonwealth of Pennsylvania, Department of Forests and Waters, Division of Hydrography.

Murphy, E.C., et al. (1905) Destructive floods in the United States in 1904. USGS Water-Supply and Irrigation Paper No. 147, USGS: Washington, DC.

Safe Harbor Water Power Corporation (1996) Ice Jam at the Safe Harbor Water Power Corporation (video), 20–23 January 1996.

USGS (1996) Statewide floods in Pennsylvania, January 1996. USGS Fact Sheet 103-96.

van der Leeden, F., F.L. Troise, and D.K. Todd (1990) *The Water Encyclopedia, 2nd edition*. Lewis Publishers: Chelsea, Michigan.

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Ice Engineering Information Exchange Bulletin

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